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EXPERIMENTS ON THE AVAILABILITY OF PHOSPHATES AND POTASH IN SOILS

BY

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

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During the years 1904 to 1906 plants have been cultivated by pot-culture methods, with and without the aid of fertilizers, in a number of soils which have been brought from different parts of India.

The principal object in view has been to test how far the chemical method, which was advanced by Dyer in 1894 for the estimation of a sufficiency or deficiency of phosphate or potash in soils (*vide* Trans. Chem. Soc., **65**., 115-167, and Philos. Trans. Royal Soc., Series B., Vol. 194, pp. 235-290) is reliable generally. This method consists in the digestion of the soil at room temperature in a 1 per cent. solution of citric acid for seven days, on six of which the mixture is agitated frequently The solution is then separated by filtration and the phosphoric acid and potash present in it determined. Although such a method is obviously empirical, Dyer standardized the value of its indications by means of a considerable number of soils of the Rothamsted Experiment Station, the agricultural value of which for certain crops is well known. The outcome of his work may be suitably quoted from the second of the papers named. "The probable limit denoting phosphatic deficiency for cereals seems to be, as deduced from this investigation, between ·01 and ·03 per cent. of citric-acid-soluble phosphoric acid in the surface soil. That is to say, a percentage as low as ·01 seems to denote an imperative demand for phosphatic manure, while as much as ·03 would seem to

indicate that there is no such immediate necessity. For root crops, especially turnips, the limit would probably be higher." (Page 269.)

" In the paper on the Hoos Field barley soils a tentative conclusion was drawn that the percentage of citric-acid-soluble potash in surface soil, indicative of potash hunger for cereals, would probably be below ·005. On considering the results of the wheat soil analyses and other results obtained in the interim by other workers who have applied the method to other soils known from other experience to be responsive to the influence of potassium salts, the author would now be inclined to modify this conclusion by suggesting that when a soil shows as much as ·01 per cent. of citric-acid-soluble potash, by this process, it may be regarded as not demanding any special application of potassium salts." (Page 275.)

There is one point which must be referred to here. One of the first questions raised, after the publication of Dyer's first paper, was in relation to calcareous soils. Obviously the calcium carbonate present in soils will forthwith react with the citric acid resulting in the formation of calcium citrate and carbonic acid, and the soil is then in contact with a solution of these substances together with any excess of citric acid.

In order to illustrate the bearing of this point, the following figures show the quantities of calcium carbonate in a soil which neutralize each tenth part of the citric acid employed; or since 10 grms. of the acid are employed per 100 grms. of soil, the figures show the percentage of calcium carbonate neutralized by each 1 grm. of the acid.

Citric acid. Grms.	Calcium Carbonate. Grms.
1	1·43
2	2·86
3	4·29
4	5·72
5	7·15
6	8·58
7	10·01
8	11·44
9	12·87
10	14·30

Thus even if the soil contains so high a proportion of calcium carbonate as 7·15 per cent., one half the citric acid remains, and the majority of soils contain considerably less than this. The Rothamsted soil, on which Dr. Dyer worked, contains only about 3 per cent. of calcium carbonate, which would alter the composition of the acid solution in only a minor degree.

Two of the soils which have been included in my experiments contained, however, upwards of 40 per cent. of calcium carbonate, and the citric acid becomes in such a case entirely neutralized.

Dr. Dyer in a postscript to his first paper recommends that in such cases an additional quantity of citric acid corresponding to the quantity of calcium carbonate " might reasonably be added to the solution." If, however, this is done with these highly calcareous soils, the soil constituents are not merely exposed to a solution of citric acid, but citric acid plus a large amount of calcium citrate, and carbonic acid. And indeed an even more important circumstance is the fact that the particles of calcium carbonate are entirely dissolved. Phosphate, which in such a soil may be present in the interior of these particles, is thus brought into actual contact with the solvent, whereas the idea underlying the use of the solvent is, that it will only be in contact with phosphates which are exposed to plant roots or soil-aqueous-solutions, *i.e.*, to phosphates which are on the *exterior* of soil particles. It is hardly, therefore, to be expected that the same result will be obtained as if the soil particles remain as far as possible intact. The circumstance emphasizes a weak point in the method. The following figures show the difference in result obtained (*a*) by the use of the usual 1 per cent. solution, and (*b*) this solution plus the extra citric acid, respectively :—

	By 1 per cent. citric acid.		By sufficient citric acid to neutralize the calcium carbonate plus the usual 1 per cent.	
	P_2O_5.	K_2O.	P_2O_5.	K_2O.
Seeraha soil containing 41·6 per cent. $CaCO_3$	·001	·008	·019	·043
Pusa soil ,, 38·63 ,,	·0003	·0062	·0015	·0085

It will be seen presently that the Seeraha soil is certainly much in need of phosphatic manure, and that potassium sulphate produced positive effects in some cases. The Pusa soil has proved to be much in need of phosphates. If then the extraction had been made with the extra citric acid, the analysis would have indicated a very doubtful requirement of phosphates in the Seeraha soil, and certainly no requirement of potash. The pot-cultures on the other hand leave no doubt that these soils respond to phosphatic manures, and the Seeraha soil probably to potash.

The literature on the subject includes two papers. One by T. B. Wood (Trans. Chem. Soc., 1896, **69,** p. 290), where evidence is produced, showing that the use of the extra quantity of citric acid would have given a result indicative of a sufficiency of readily available phosphates, when in fact the soil responded to phosphatic manures ; the other by Cousins and Hammond (Analyst, 1903, **28,** 238), where the evidence indicates the desirability of using the extra citric acid. This latter evidence relates, however, to land bearing bananas, a crop so entirely different from cereals that a quite different "limiting figure" may be applicable.

It is unfortunate that the conclusions on the subject are so contradictory. It seems to me preferable to adhere to the use of the simple 1 per cent. solution, and if, when it is applied to any particular class of soils, the limiting figure for phosphate or potash, as proved by actual trials with plants, is shown to be different from that which Dyer deduced with the Rothamsted soils, to then adopt this particular limiting figure. It is to be recollected that the method is not merely empirical, but that a limiting figure which is applicable to one description of plant, will not necessarily apply to another plant of widely different botanical character, period of growth, root range, etc. Dyer himself emphasized that the limiting figure he found would not necessarily apply to other crops than cereals, and "that for root crops, especially turnips, the limit would probably be higher" (*vide* ante).

It must be held to be a matter for regret that nearly all who have proposed methods for the estimation of available plant

food, have employed an acid as the solvent. Such solvents necessarily attack the surface of the particles in a manner wholly different from the neutral solutions present in the soil, and as has been pointed out, dissolve up particles of calcium carbonate entirely, thus exposing plant food to the solvent, which in the soil is present in the *interior* of particles. No doubt the quantity of material, which a neutral solvent will dissolve, is much less than would be brought into solution by an acid solvent, and difficulties arise in the determination of such minute quantities, but the fundamental defect attaching to acid solvents nevertheless remains.

The soils which have been subject to experiment at Dehra Dun and (later) at Pusa, comprise the following :—

Soil.	Containing :—		
	Organic Nitrogen. %	Available. P_2O_5 %	Available. K_2O %
Dehra Dun	·181	·146	·022
Seeraha-Behar	·046	·001	·008
Pusa-Behar	·060	·0003	·006
Shillong G	·228	·011	·010
,, B	·193	·005	·012
Bangalore	·059	·0047	·0023
Godavari V	·071	·042	·010
,, R	·084	·011	·005

For cereals, which have so far been principally included, the Dehra Dun soil would be considered sufficiently well supplied with phosphates and potash, and the Godavari V soil probably so ; the other six soils would be expected to respond to phosphates, and four, namely, Seeraha, Pusa, Bangalore and Godavari R to potash.

The first two years' experiments were made while the chemical laboratory was at Dehra Dun, where the conditions for this class of work were in many respects opposed to accuracy. Only a thatched hut was available, and the cultivation jars had to be moved by hand ; nor was any means available for maintaining the moisture very constant, such we now have. But the chief obstacle

proved to be rats and squirrels, which could not be kept away at night and damaged in great measure many of the mature plants.

In some of these cases an estimate of the weight of the entire plants was obtained when their number was reduced in each jar, and these figures aid in drawing conclusions.

The experiments of 1906 made at Pusa were free from such untoward incidents and are in consequence more reliable.

The details are set out in the following pages, but a graphic summary may be here inserted. If the sign + is employed to denote a positive result, whilst the sign − a negative one, ± where the outturn of grain is negative, but that of total dry matter positive, and ? where the indication is doubtful, the nett results will be seen at a glance.

	PHOSPHATE:		POTASH:	
	Expected.	Realized.	Expected.	Realized.
Dehra-Dun	−	−	−	.....
Seeraha Behar	+	+ + ± +	?	+ + ±
Pusa-Behar	+	+	+	... ..
Shillong G	+	− + +	−	+ + +
,, B	+	− − +	−	− − −
Bangalore	+	+ + +	+	− + −
Godavari V	−	− ± +	−	− − +
,, R	+	+ ± +	+	− ± ±

This representation shows that great dependence may be placed on Dyer's method, as also his limiting figure for phosphates even in soils of a widely different nature. In the whole list, the cultivations have yielded a contradictory result in two cases. The Shillong B soil should have been benefited by phosphates, and if dependence were placed on the experiments at Pusa (carried out with the more perfect appliances), this exception would disappear. The Godavari V soil should hardly have responded to phosphatic manures, whilst it has done so to a greater or less extent.

The effect of potash is similarly characterized by contradictory results in two cases. The Shillong G soil has shown a

positive result where it was hardly to be expected. Dyer's test yielded ·01% K_2O which is his limiting figure. The Bangalore soil should have given a positive result with potash manure, but has done so with only one crop out of three. It is always to be recollected that neither Dr. Dyer nor other experimenters have advanced this method as an absolute one for determining whether it will pay to apply specific fertilizers. On the contrary, it has been regarded as one which must necessarily be employed with some caution. Our knowledge of the nature of the phosphates and the potash compounds which actually exist in the soil is most imperfect, and, as Hall and Amos (Trans. Chem. Soc., 1906, **89**, p. 205), have pointed out, the amount of a soil constituent which passes into solution in a given time depends not only on its nature but also on its mass. Soils in different parts of India differ very widely in composition, and whilst we may apply the 1% solution to them without exception, it does not follow that the same limiting figure will apply equally to all. Finally, the nature of the plant which is grown must always play an important rôle in relation to this limiting figure.

Nevertheless, and although I make these several reservations, there cannot be any doubt that the method is proving generally useful for ordinary agricultural land, enjoying a rotation of crops, one of which is usually a cereal, and that the limiting figure proposed by Dyer is much more generally applicable than might have been expected.

The details of the experiments are set out in the following paragraphs.

Dehra Dun Soil.

This soil is derived from shale and limestone of the Himalayas and is a rich soil with excellent physical characteristics.

The chief analytical data are as follows :—

	Per cent.
$CaCO_3$	·41
Total P_2O_5	·366
Available P_2O_5	·146
Available K_2O	·022
Organic Nitrogen	·181

It was only employed in one season's experiments when wheat and gram were grown. The outturns were as follows :—

Manure.	Weight of whole crops (grms.).	
	1903-4 Wheat.	1903-4 Gram.
Nil	37·6	45·5
Nitrate	62·0	45·0
Nitrate and phosphate .	64·3	43·0

The same is set out graphically on the chart No. 1.

The Seeraha Soil.

This soil is representative of a large area in Behar and possesses two chief characteristics ; firstly, it consists entirely of very fine material, and like the whole Indo-Gangetic alluvium contains no stones ; secondly, about one-third of it is chalk.

The following are the chief analytical data :—

$CaCO_3$	41·6
Total P_2O_5	·097
Available P_2O_5	**·001**
Available K_2O	**008**
Organic Nitrogen	·046

It was employed during four seasons, the crops being cereals in each case. The results are set out in the following statement and on chart No. 2, from which it is evident that both phosphate and potash had a definitely positive effect.

Manure.	Weight of whole crop (grms.).				Weight of grain (grms.).			
	1903-4 Wheat.	1904 Murwa.	1904-5 Wheat.	1906 Kodo.	1903-4 Wheat.	1904 Murwa.	1904-5 Wheat.	1906 Kodo.
Nil	2·4	13·3	4·6	24·7	·7	5·4	1·6	12·3
Nitrate	2·1	63·9	11·5	43·9	·6	20·4	6·4	22·7
Nitrate and phosphate ..	8·3	63·8	20·0	62·4	2·5	26·9	5·9	30·0
Nitrate, phosphate and potash	...	80·3	26·5	...	...	29·1	7·9	...

The Pusa Soil.

This is similar in all respects to the Seeraha soil, but was first included in the experiments in the rainy season of 1906.

The chief analytical data are as follows :—

$CaCO_3$	38·63
Total P_2O_5	·10
Available P_2O_5	**·0003**
Available K_2O	**·0062**
Organic Nitrogen	·060

The crop grown was Kodo (Paspalum scrobiculatum), and the yields were as follows :—

Manure.	Weight of whole crop (grms.).	Weight of grain (grms.).
Nil	41·4	18·7
Nitrate	69·8	20·8
Nitrate and phosphate ...	86·1	27·7

The chart No. 3 illustrates the same result. The same soil has been utilized for similar experiments during the current season, wheat being the crop, and the effect of phosphate is even more marked. The effect of potash was not tested in the rainy season of 1906, but judging by the present season's plants its effect will be negative.

Bangalore Soil.

This is derived from the laterite, and is consequently highly ferruginous. It holds only a low proportion of water. When wet, it drains readily, but at the same time contains so much plastic material, that it is adhesive when damp. The chief analytical data are :—

$CaCO_3$	·066
Total P_2O_5	·052
Available P_2O_5	**·0047**
Available K_2O	**·0023**
Organic Nitrogen	·059

Cultivations were made during three seasons, namely, the monsoons of 1904 and 1906 and the "cold weather" of 1904-05; the crops being Murwa (Eleusine coracana) in the former, wheat in the latter. The plants of the first two seasons were interfered with by the depredations of squirrels and rats, and ultimately the only dependable index of the effect of the manures was the estimated weight of green plants at the time the number of plants in each jar was reduced. It is clear that the phosphate had produced a positive effect at this time, and the cultivations of 1906, which were free from such errors as the above, leave no doubt of this. The effect of potash has been however much less certain, although one might have anticipated a positive result.

The weights of plants were as subjoined and the chart No. 4 refers to them also.

WEIGHT OF CROPS (GRMS.).

Manures.	1904 Murwa.	1904-05 Wheat.	1906 Murwa.
Nil	4·4	·51	10·6
Nitrate	4·15	1·66	39·1
Nitrate and phosphate ...	6·05	1·88	63·3
Nitrate, phosphate and potash	5·02	2·08	43·3

SHILLONG SOILS.

Two soils had been received from Shillong, the one being considered good, the other distinctly infertile. Examination in the chemical laboratory revealed nothing which would account for such a difference. Apart from other characteristics, they have proved to be very similar in their productive powers, and the difference noticed at the place of origin has not at any time exhibited itself in my experiments; both soils have proved to be very fertile. For purposes of differentiation their titles of "good" and "bad" have been retained. They are chiefly characterized by a high proportion of organic matter (3·09 per cent. organic

carbon) and great waterholding capacity. The chief analytical data are as follows :—

		"Good" soil.	"Bad" soil.
$CaCO_3$	...	·088	·025
Total P_2O_5	...	·069	·059
Available P_2O_5	...	**·011**	**·005**
Available K_2O	...	**·010**	**·012**
Organic Nitrogen	...	·228	·193

Murwa was cultivated in the monsoons of 1904 and 1906, and wheat in the cold weather of 1904-5. Like the corresponding plants of the Bangalore soil, these suffered from attacks by rats when the wheat was ripening, and the only index remaining of the effect of the fertilisers was the estimated weight of the green plants when the number in each jar was reduced. The effect of phosphates in these soils is doubtful, whereas it should have been positive in both. This may in part be due to the absence of nitrogenous manure. In other experiments it has frequently been observed that, even though a soil is deficient in available phosphate, a positive effect of this plant food will only be realized if a nitrogenous fertilizer is added at the same time. In such cases, however, there was likewise a deficiency of nitrogen in the soil, and the combined effect of the fertilizers has been just what is found on similarly characterized plots at Rothamsted and Woburn. But when these pot cultures were commenced, the anticipation was that the Shillong soils were so well supplied with nitrogenous organic matter that added nitrate would have little or no effect, and with the limited amount of soil available the distribution of fertilizers was made on this basis. Later, after the effect of the "complete" fertilizer was observed, it was too late to re-arrange the treatment. For several reasons the most reliable result is that obtained in the new pot culture house at Pusa, and with that season's experiment phosphate had a distinctly positive effect. I consider it probable therefore that the indication provided by the analytical method in 1903 was correct and that phosphates would generally react positively with

this soil. The yields are as subjoined and are also illustrated by chart No. 5.

Shillong Soils.

Manures.	"Good."			"Bad."		
	1904 Murwa.	1904-5 Wheat.	1906 Murwa.	1904 Murwa.	1904-5 Wheat.	1906 Murwa.
	Weight of whole crop (grms.).					
Nil	52·2	·36*	31·8	42·5	·57*	32·4
Phosphate	40·1	·56*	33·7	50·0	·53*	41·8
Potash	57·5	·45*	43·2	49·5	·54*	31·1
Phosphate, potash and nitrate	74·7	·80*	69·1	56·2	1·06*	74·4
	Weight of grain (grms.).					
Nil	16·7	...	12·0	15·1	...	12·9
Phosphate . ..	16·1	...	16·8	15·6	...	17·5
Potash	19·2	..	16·2	14·7	...	11·6
Phosphate, potash and nitrate	30·0	...	26·5	19·7	...	28·6

* Estimated weight per plant on January 18th, 1905.

The Godavari Soils.

The soil of the Godavari Delta is largely black cotton soil of a very stiff tenacious type and is probably alluvium brought from the similar tracts of the Indian plateau. It was known that much of this land contained low proportions of lime and phosphate as determined in the laboratory, and sufficient earth was sent from two villages for three or four jars. But these portions contained rather more phosphate than was anticipated. The following are the analytical data :—

	Vadlamur.	Ragampeta.
$CaCO_3$	·179	·134
Total P_2O_5	·143	·119
Available P_2O_5 . .	**·042**	**·011**
Available K_2O ...	**·010**	**005**
Organic Nitrogen	·071	·084

Cultivations were made during three seasons, and the yields are set out in the subjoined statement and on chart No. 6.

Godavari Soils.

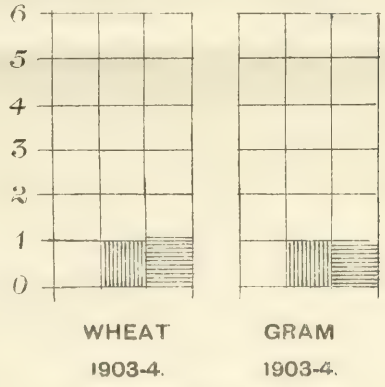
Manures.	Vadlamur.			Ragampeta.		
	1904 Murwa.	1904-5 Wheat.	1906 Murwa.	1904 Murwa.	1904-5 Wheat.	1906 Murwa.
	Weight of whole crop (grms.).					
Nitrate	45·8	18·9	57·0	32·4	22·0	66·4
Nitrate and phosphate ..	29·8	22·2	83·0	28·9	29·0	83·0
Nitrate, phosphate and potash	41·0	23·9	89·1	28·0	26·0	77·2
	Weight of grain (grms.).					
Nitrate	7·5	6·0	24·9	5·2	6·2	31·6
Nitrate and phosphate ...	5·9	5·2	37·4	7·1	5·7	38·5
Nitrate, phosphate and potash	6·0	4·0	39·0	6·2	5·5	31·1

These soils have given the least dependable data of any in the series; "Vadlamur" should hardly have given a positive reaction with phosphate; "Ragampeta" should have done so. As the data show, they have both reacted similarly, the first crop was negative, the second doubtfully positive, the third distinctly positive. The latter, grown under the much more satisfactory conditions at Pusa, is the most reliable.

CHART No. 1.

DEHRA DUN SOIL.

RELATIVE YIELD OF TOTAL CROP



NO MANURE.

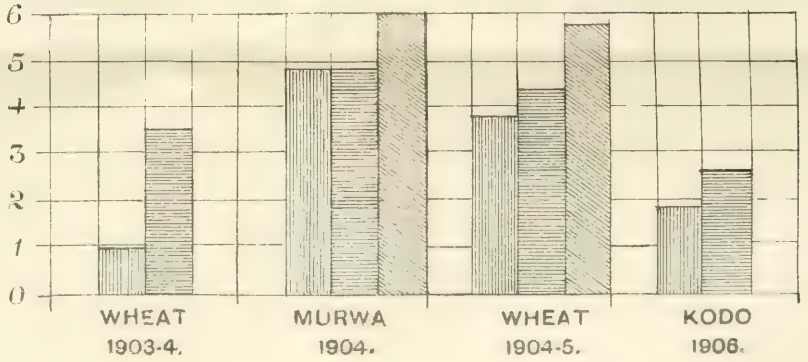
NITROGEN ONLY.

NITROGEN PLUS PHOSPHATE

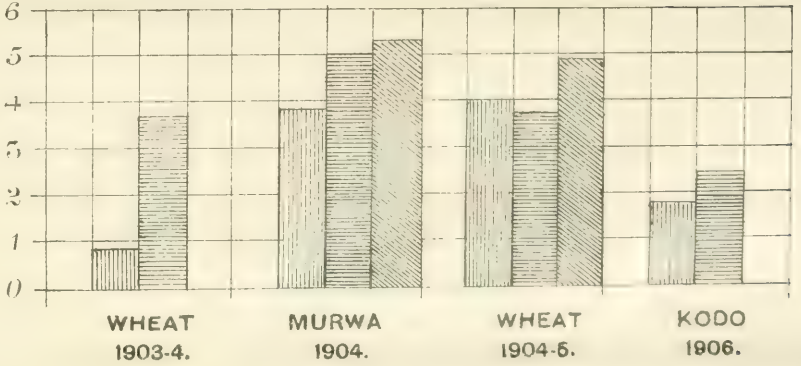
CHART No. 2.

SEERAHA SOIL.

RELATIVE YIELD—TOTAL CROP



RELATIVE YIELD—GRAIN.



NO MANURE.

NITROGEN ONLY.

NITROGEN PLUS PHOSPHATE.

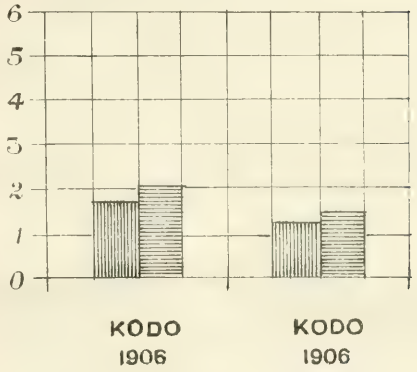
NITROGEN PLUS PHOSPHATE PLUS POTASH.

CHART No. 3.

PUSA SOIL.

RELATIVE WEIGHTS

OF TOTAL CROP OF GRAIN

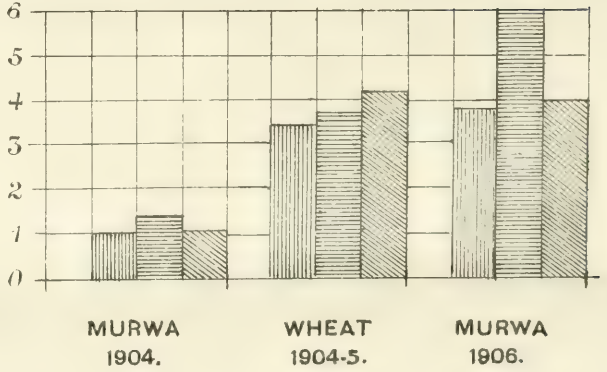


NO MANURE.
NITROGEN ONLY.
NITROGEN AND PHOSPHATE.

CHART No. 4.

BANGALORE SOIL.

RELATIVE WEIGHT OF TOTAL CROP

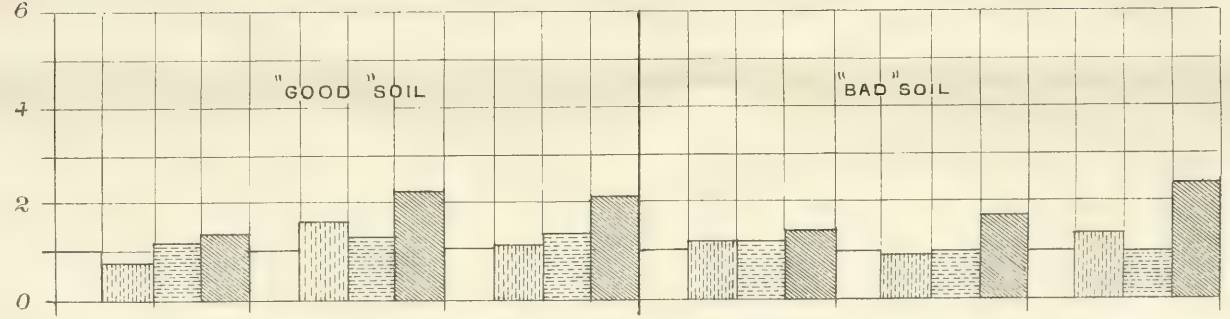


NO MANURE.
NITROGEN ONLY.
NITROGEN AND PHOSPHATE.
NITROGEN, PHOSPHATE AND POTASH.

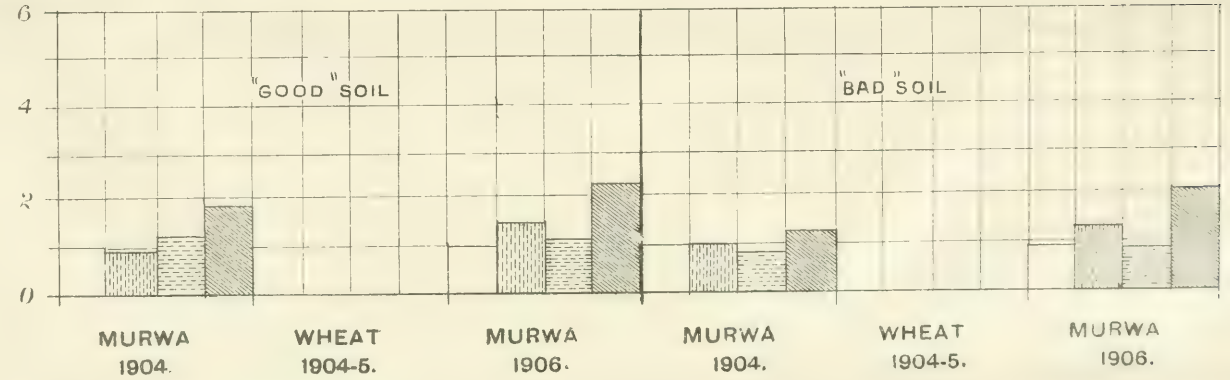
CHART No. 5.

SHILLONG SOILS.

RELATIVE YIELD—TOTAL CROP.



RELATIVE YIELD—GRAIN.



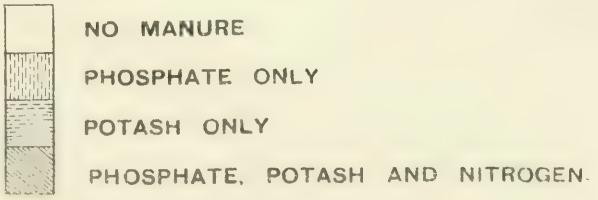
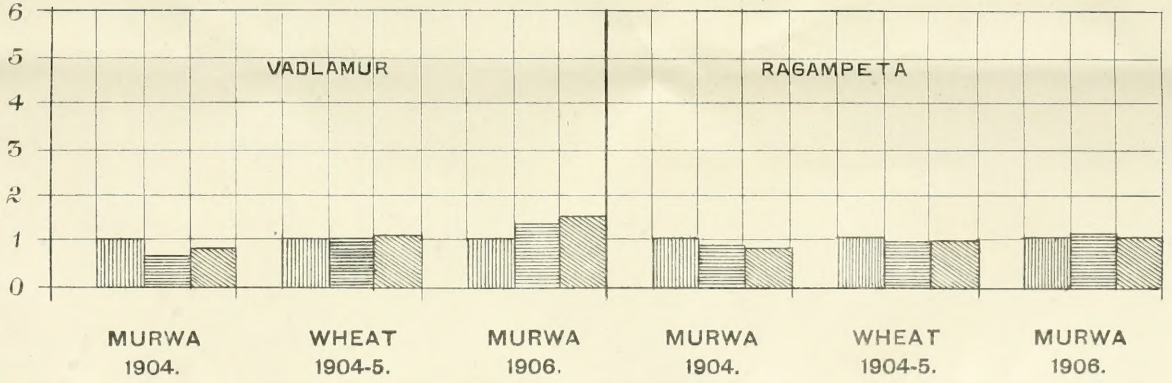


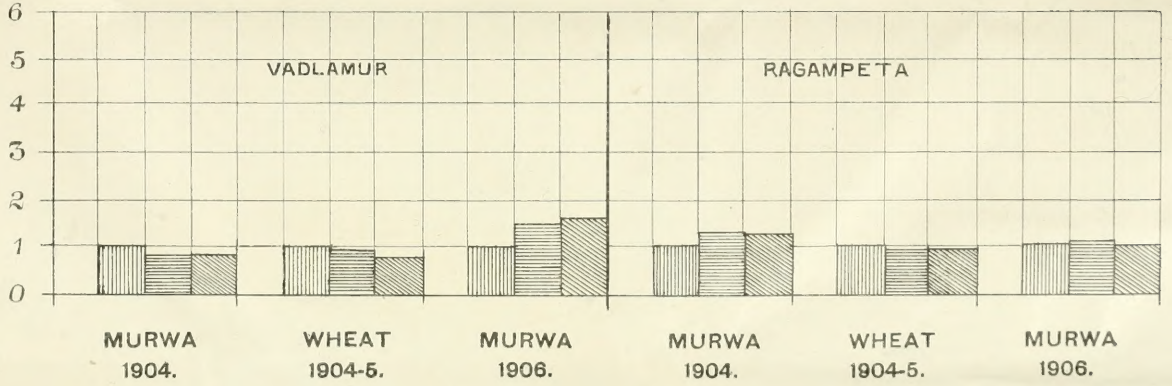
CHART No. 6.

GODAVERI SOILS.

RELATIVE WEIGHT OF TOTAL CROP.



RELATIVE WEIGHT OF GRAIN.



NITROGEN ONLY.

NITROGEN AND PHOSPHATE.

NITROGEN, PHOSPHATE AND POTASH.

NOTICE.

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